SPECTRAL REFLECTANCE VERSUS ABUNDANCES OF MINERALS AND GLASSES IN THE 10 TO 45 MICRON SIZE FRACTION OF MARE SOIL 12030.

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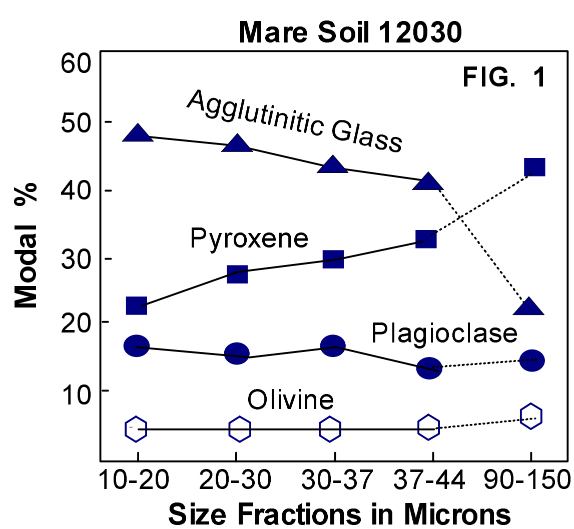
The foundation for remote mineralogical analysis lies in the physics underlining optical absorption and the linking of spectral properties of materials measured in the laboratory to well-understood mineral species and their mixtures. The lunar samples returned by the Apollo missions have provided the "ground-truth" for evaluation of spectral characteristics of the Moon. Accurate estimation of rock and mineral compositions is complicated by the nature of the pervasive lunar soil (<1 cm fraction of the regolith), which contains the cumulative optical effects of "space weathering," including impact-produced glass and agglutinates (aggre-gates of rock and mineral fragments bonded together by impact-produced glass). In order to make a more direct and quantitative link between soil mineralogy and spectral properties, we have initiated a program to: 1) obtain accurate measurement and characterization of the petrography of lunar soils (in terms relevant to remote analyses), coupled with 2) measurement of precise reflectance spectra and testing and use of appropriate analytical tools that identify and characterize individual mineral and glass components (through spectral deconvolution of a mixture). Reflectance + modal abundance data on 9 lunar soils of contrasting maturities from all the Apollo mare sites will be obtained and modelled. We report here on the first of these soils, 12030.

As noted by McCord and Adams [1] and described by Fischer and Pieters [2], the three principal optical manifestations of space weathering of lunar materials are: 1) overall reduction of reflectance; 2) general attenuation of diagnostic absorption bands; and 3) development of a red-sloped continuum. These effects increase with soil maturity (i.e., surface exposure). A principal cause for these variations is believed to be accumulation of "single-domain native Fe" (newly termed 'nanophase Fe') present in the finest fraction of the lunar soils, and models are being developed to characterize the effects of agglutinitic glass on optical properties [e.g., 2-5]. It is the finest size fractions of the bulk lunar soil that dominate the observed spectral signatures[3]. This is because fine particles coat larger particles and photons that enter large particles are less likely to escape. Optically, the 10-20 μm and 20-45 μm size fractions are the most similar to the bulk soil [4]. Larger size fractions are not representative of bulk soil properties[3], and the <10μm fractions appear to be highly unusual [4]. However, the detailed petrographic properties of lunar soils, particularly the finer fractions most relevant for remote spectroscopy, are poorly known.

METHODOLOGY - Standard point-counting methods are inadequate for determining the modal abundances of minerals and glasses in fine (<75 μm) size fractions. This is because at fine grain sizes (needed to link with the reflectance measurements), the agglutinates are largely broken up into individual mineral and glass grains, thereby losing their identifying characteristics (e.g., vesicles, inclusions). Using an Oxford Instrument Energy Dispersive Spectrometer Unit (EDS) on a Cameca SX-50 electron microprobe at the University of Tennessee, we have recently established the software and chemical/shape parameters with which to perform X-ray digital-imaging analyses on grain mounts of lunar soils. We thereby produce accurate modal analyses of individual mineral and glass components, independent of their associations in the soil particles. The details of this technique are given in Taylor et al. [6], and are an outgrowth of techniques illustrated by Taylor et al. [7], Chambers et al. [8-9], and Higgins et al. [10-12].

Spectra of all soils and size separates were measured using the bi-directional reflectance spectrometer of RELAB. Emphasis was on characterizing the absorption features in a regular, quantitative manner. We first used the standard band analysis method developed for previous lunar spectra [13-14], as described by Clark & Roush [15]. This provides approximate, but reproducible, data on continuum, band centers, and band depth. We then used the more sophisticated modified Gaussian model (MGM) developed by Sunshine et al. [16-17] to simultaneously solve for continuum and absorption band parameters (center, width, strength).



MARE SOILS - Taylor et al. [6] examined the 90-150 µm size fraction of 9 lunar soils from all Apollo mare sites, using X-ray digital-imaging analyses. These soils were chosen because they represent different compositions and contrasting maturities, as depicted by I_s/FeO values [18]. These mare soils are the same ones that are intended for investigation in our newly initiated program. Prior study of these soils [6] has provided significant insight into the difficulties of distinguishing the various glass types. Mare soil 12030, the first in our series and the subject of this paper, is immature with I_s/FeO of 14 and represents a typical immature low-Ti basaltic soil. It was sized dry using a Sonic Sifter®, and samples were taken for spectral reflectance measurements and for preparation of a polished grain mount for modal analyses.

MODAL ABUNDANCES - As shown in Figure 1, there appears to be a slight increase in plagioclase with decreasing grain size, supporting the F^3 model [19]. In contrast, there is a distinct decrease in pyroxene with decreasing grain size. However, the most important change in modal abundance is for agglutinitic (i.e., impact-produced) glass. There is over a 2-fold increase in this glass between the 90-150 µm and 10-20 µm size fractions. Even between the 37-44 µm and the 10-20 µm fractions, there is a 20 vol.% increase in agglutinitic glass. It was stated by Labotka et al. [20], Simons et al. [21], and more recently by Fischer [4] that the abundance of agglutinates decreases as grain size decreases. These latest results are in direct contrast to previous studies. ***The modal amount of agglutinitic glass increases in lunar soils as grain size decreases.*** It is this glass which contains the nanophase, single-domain Fe^o, and which is responsible for the general increase in I_s/FeO with decrease in grain size, as reported by Morris [22].

REFLECTANCE - The reflectance spectra for the 4 size fractions and a separate bulk sample of soil 12030 are shown in Figures 2 & 3. The spectra in Fig. 3 are scaled to unity at a wavelength of 0.75 µm. Notice that the <30 µm fractions most closely resembles the bulk soil, similar to the findings of Fischer and Pieters [5]. There is an overall reduction of band strength and increase in red-slope continuum with decrease in grain size. This increase in red-slope continuum is similar to that which generally occurs as lunar soils mature and is related to the increase in agglutinitic glass. The absorption band at 0.9-1.0 µm is due to Fe^{2+} in pyroxene. As is commonly observed for pyroxene-bearing materials, there is a decrease in the ferrous absorption strength with decreasing particle size, associated with an overall reduction of mean path length. However, for lunar soil 12030, there is also a notable decrease in relative pyroxene abundance with decreasing particle size (Fig. 1). The band strength for the optically dominant, finest size fractions is thus reduced for three reasons: 1) normal decrease of band strength with decreasing particle size and path length; 2) increasing abundance of absorbing agglutinitic glass; and 3) decrease in pyroxene abundance.

SUMMARY -- Although our mare soil study is at the preliminary stage of analysis, we are encouraged by these initial results which provide an explicit documentation of optically active minerals and alteration components in lunar soils.

REFERENCES: 1 = McCord & Adams, 1973, Moon 7, 453; 2 = Fischer & Pieters, 1994; 3 = Pieters et al., 1993, Remote Geochemical Analysis, 309; 4 = Fischer, 1995, Ph.D., Brown Univ.; 5 = Fischer & Pieters, 1996, JGR, 2225; 6 = Taylor, 1996, Icarus 124, 5596; 7 = Taylor et al., 1993, LPSC 24, 1409; 8 = Chambers et al., 1994, Space 94, ASCE, 878; 9 = Chambers et al., 1995, JGR 100, 14,391; 10 = Higgins et al., 1995, LPSC 26, 601; 11 = Higgins et al., 1996, Meteor. Planet. Sci. 31, 356; 12 = Pieters, 1982, Science 215, 59; 13 = Pieters, 1986, Rev. Geophys. 27, 554; 14 = Clark & Roush, 1982, JGR 89, 6329; 15 = Sunshine et al., 1990, JGR 95, 6955; 16 = Sunshine et al., 1993, Icarus 105, 79; 17 = Morris, 1976, PLPSC 7th, 315; 18 = Walker & Papike, 1981, PLPSC 7th, 421; 19 = Labotka et al., 1980, PLPSC 11th, 1285; 20 = Simon et al., 1981, PLPSC 12th, 371; 21 = Morris, 1977, PLPSC 8th, 3719.